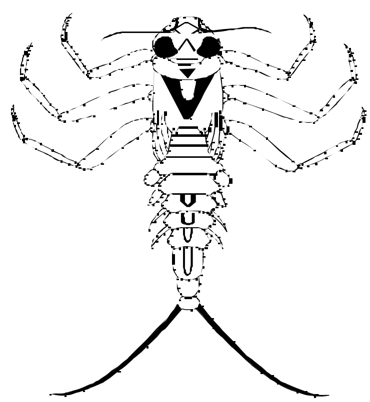
Bio-monitoring of Water Quality Using Aquatic Invertebrates and In-stream Habitat and Riparian Condition Assessments: Status Report for the Niobrara River, Agate Fossil Beds National Monument, Nebraska 1989-2004



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1.0 INTRODUCTION

The National Park Service (NPS) began monitoring aquatic invertebrates of the Niobrara River within Agate Fossil Beds National Monument, Nebraska in 1988. However, it was not until 1989 that the current sampling method was implemented (Harris et al. 1991). Sporadic sampling between 1992 and 1995 was done through funding provided by the Midwest Regional Office of NPS. However, most of this sampling was completed outside the season of interest for this report, summer. Concerted monitoring efforts began again in 1996-1997, following creation of the Prairie Cluster Prototype Long-term Ecological Monitoring Program, now known as the Heartland Inventory and Monitoring Network and Prairie Cluster Prototype Monitoring Program – a base-funded science program to monitor natural resources at Agate Fossil Beds National Monument and sixteen other Midwestern NPS units. The purpose of this report is to summarize aquatic invertebrate monitoring data collected from 1989 through 2004, and to assess changes in community structure through time. In-stream habitat and riparian assessments were conducted in 2002 and 2003 to document habitat conditions of the Niobrara River where the aquatic invertebrate communities evolved. Results of this effort are reported as well.

Benthic invertebrates are the most common group of organisms used to assess water quality (Rosenberg and Resh 1993). They are attractive as indicators because they represent a diverse group of long-lived, sedentary species that react strongly and often predictably to human influences on aquatic systems (Cairns and Pratt 1993). The objectives of this bio-monitoring program are to determine the annual status of stream invertebrate communities in order to assess the water quality of the Niobrara River and to detect changes through time in aquatic invertebrate communities. In-stream habitat and riparian condition assessment aid in interpreting results from our aquatic invertebrate monitoring effort.

1.1 Background

The Niobrara River originates near Lusk, Wyoming, traverses the northern half of Nebraska from west to east and empties into the Missouri River near Niobrara. The entire river basin encompasses over 30,000 km^2 with approximately 2200 km^2 above Agate Fossil Beds National Monument. The Niobrara River meanders through the center of the park with a marshy flood plain encompassing nearly 187 ha of the park.

Natural vegetation of Agate Fossil Beds National Monument is mixed-grass prairie with the Kuchler (1964) potential natural vegetation reported as blue grama *Bouteloua gracilis*, needlegrass *Stipa comata*, and western wheatgrass *Agropyron smithii* (Stubbendieck and Willson 1986). Irrigated dry-land farming, mostly alfalfa hay is practiced in the watershed surrounding the park. However, the primary land use in the watershed is cattle grazing. The park is on the boundary of two of Omernick's (1987) ecoregion, Western High Plains and Northwestern Great Plains. The area is underlain with permeable sand and sand-rock to 150 m in depth and of Tertiary age (Harris et al. 1991). Average annual rainfall is 369 mm per year with the highest monthly precipitation occurring in May, the lowest in December (Harris et al.1991).

Pollution History.--Water pollution from industrial or municipal effluent in the watershed above Agate Fossil Beds National Monument is largely unknown. A cattle feedlot borders the park on the west side. Water Resources Division (WRD), National Park Service conducted an extensive review of historic water quality data (1952 - 1993) for an area four point eight kilometers upstream and one point six kilometers downstream of the monument (Water

Resources Division 1999). Water Resource Division identified one period in October 1952 when pH equaled the upper limit of EPA's chronic criteria for freshwater aquatic life. Since 1973, fecal coliform concentrations equaled or exceeded WRD bathing-water screening criterion four times. However, these four samples may have been held longer then the standard culture time before analysis. Cadmium was found to exceed EPA's acute freshwater criterion and equal their drinking water criterion in February 1992. Copper exceeded EPA's acute freshwater criterion in August 1991. Lead exceeded or equaled EPA's drinking water criterion in November 1991 and February 1992, respectively. From the results of WRD's review it is apparent that water quality of the Niobrara River within Agate Fossil Beds National Monument is high and relatively non-impaired. Monitoring efforts prior to 1952 were not identified in the WRD report (1999) or for this report.

2.0 METHODS

2.1 Aquatic Invertebrate Sampling

The details of field and laboratory procedures for aquatic invertebrate sampling are described in Peterson et al. (1999), and summarized below.

Monitoring Sites.--Harris et al. (1991) established three monitoring sites within the park, along the Niobrara River (Figure 1). However, the middle site was not monitored until 1997. Five replicate Hester-Dendy samples were collected at each site during each sampling event. An in-stream habitat and riparian condition assessment reach was co-located with the middle aquatic invertebrate sampling site.

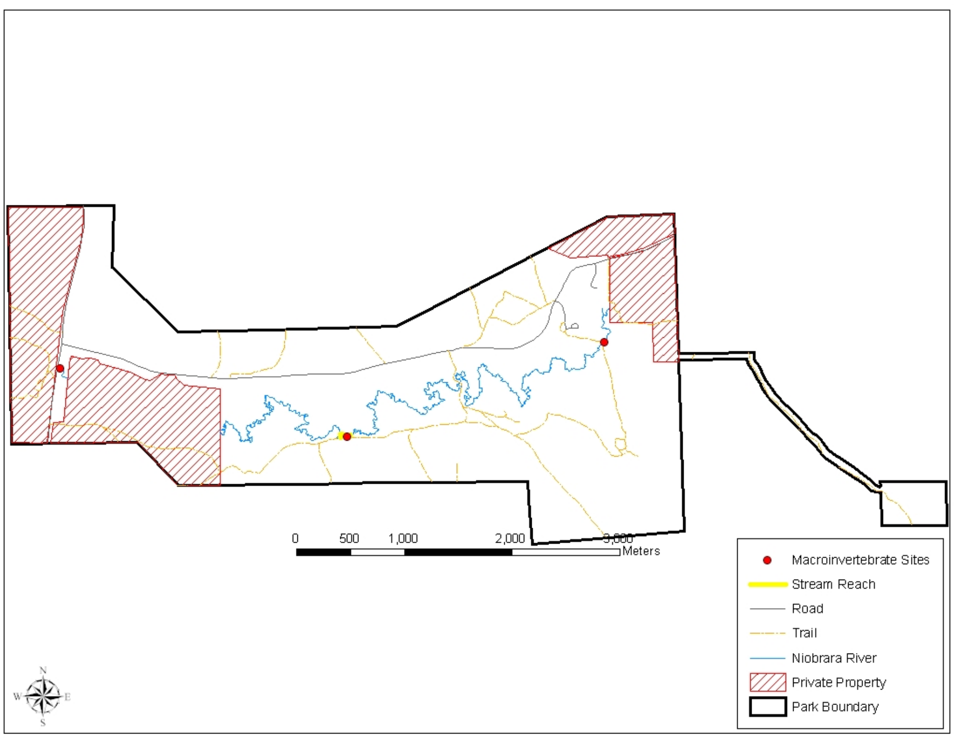

Figure 1. Aquatic invertebrate and in-stream habitat and riparian condition assessment sites on the Niobrara River at Agate Fossil Beds National Monument, Nebraska.

Sampling Frequency And Timing.--The monitoring protocol calls for the collection of three samples, with five replicates per sample, at approximate monthly intervals during a summer sampling window defined by growing degree days (i.e. days with average daily temperature above 10°C). For Agate Fossil Beds National Monument, normal average daily temperatures fall within this range for the period 18 June through 19 September (National Weather Service). The samples included in this report were collected between 2 July and 29 September, samplers were deployed one month prior to collection dates. In-stream habitat and riparian condition assessments were conducted during July.

Field Sampling.--Benthic invertebrate samples were collected from the stream with Hester-Dendy samplers following methods outlined by Peterson et al. (1999). Invertebrates were carefully removed from the samplers and placed in labeled jars containing 80 % ethyl alcohol. Samples were then prepared for shipping and sent to a lab for species identification and enumeration.

Colorado State University investigators collected aquatic invertebrate samples in 1989 (Harris et al. 1991). Park staff collected invertebrate samples for the period 1996-2004.

Aquatic invertebrates were identified and enumerated by Dr. Boris Kondratieff’s lab, Colorado State University for the period 1989 (Harris et al. 1991); and by Dr. Charles Rabeni’s lab, Missouri Cooperative Fish and Wildlife Research Unit, University of Missouri-Columbia for 1996-2004. Invertebrates were identified to the lowest taxonomic level possible, which was generally to genus.

To insure the consistency of data collected in the future, NPS personnel at Agate Fossil Beds National Monument will continue to collect five replicate aquatic invertebrate samples from each of three sites, three times annually. Additionally, physical and chemical parameters will continue to be measured each time a sample is collected. In-stream habitat and riparian condition assessments will be conducted again in 2007-2008 and every five years thereafter.

Community Indices.--The monitoring protocol recommended using a suite of four community indices to describe changes in community structure (Table 1; Peterson et al. 1999). Peterson (1996) identified four metrics to be the least redundant and most indicative of water quality from a list of nine possible metrics using Pearson correlation comparisons and a Principal Components Analysis of the correlation matrix. Additionally, we included Genus Evenness and EPT Richness in this report for the purposes of comparison with aquatic invertebrate monitoring data from other sources.

Table 1. Metrics used to characterize the aquatic invertebrate communities of the Niobrara River, Agate Fossil Beds National Monument, Nebraska and chosen as indicative of changing water quality through time. An asterisk indicates metrics originally selected by Peterson (1996).

Metric (Reference)	Definition	Expected Response
Density* (Plafkin et al. 1989)	Number of all individuals present per sample. Reported as individuals per m^2	Lower aquatic invertebrate densities indicate that a stream may have been subjected to one or more stresses.
Family Biotic Index* (Hilsenhoff 1988)	$FBI = \Sigma n_i a_i / N$ N is the total number of individuals in a sample, n_i is the total number of individuals in a family, and a_i the tolerance value for the *i*th family.	Higher FBI indicates that a stream may have been subjected to one or more stresses. This index weights the relative abundance of each family by its relative pollution tolerance value to determining a community score. Therefore, pollution-tolerant species are weighted heavier than pollution-sensitive species in the index.
Genus Diversity* (Shannon-Wiener Index: Shannon and Weaver 1949)	$H' = -\Sigma(n_i / N)*\ln(n_i / N)$ N is the total number of individuals in a sample and n_i is the total number of individuals in the *i*th genera.	Lower diversity indicates that a stream may have been subjected to one or more stresses.
Genus Richness* (Resh and Grodhaus 1983)	Number of genera present per sample.	Lower richness indicates that a stream may have been subjected to one or more stresses.
Genus Evenness (Pielou 1966)	A measure of how evenly the total number of individuals are distributed across each genera. $J' = H'/\ln(\text{genus richness})$	Lower evenness indicates that a stream may have been subjected to one or more stresses and is being populated disproportionately by a few genera, usually pollution tolerant genera.
EPT Richness (Resh and Grodhaus 1983)	Number of Ephemeroptera, Plecoptera, and Trichoptera taxa present per sample.	Lower richness indicates that a stream may have been subjected to one or more pollution stresses. In general, the majority of taxa in these three orders are pollution sensitive.

2.2 In-stream Habitat and Riparian Condition Assessment

Details on procedures for assessing in-stream habitat and riparian condition are described in Peitz (draft), and summarized here. Eleven transects spaced equal distances apart along a 150-m reach were used to assess in-stream habitat and riparian condition. The first two transect were located downstream of the middle aquatic invertebrate sample site. The third transect was located at the sample site with the remaining eight upstream at 15-m intervals. Water quality measurements, dissolved oxygen, conductivity, pH, temperature and water clarity were taken at a representative location along the reach before entry into the stream to complete other assessment work. This kept observers from impacting water quality results. Dissolved oxygen (DO) and temperature were measured using an YSI 55 meter. Conductivity, relative conductivity and pH were measured using a YSI 63 meter. Water clarity or cloudiness caused by suspended or dissolved materials in the water was measured using a 120 cm Secchi tube.

In-stream discharge, flow stage, fluctuation rating and channel morphology were assessed and recorded for the stream reach at the completion of all in-stream habitat and riparian condition assessments. The presence and type of channel alterations as well as sedimentation and excessive algae problems was noted. Also noted was the amount and date of all recent rains if any. Pools located within the reach were recorded as belonging to one of four classes depending depth: class 1, pool > 3 ft; class 2, pool > 2 ft; class 3, pool >1 ft; and class 4, pool is shallow and pool/riffle/run/bend ratio determined. Channel sinuosity and a stream degradation rating were determined for the reach.

In-stream habitat and riparian condition parameter were assessed at each transect and results recorded in one of three categories; in-stream, stream bank or riparian zone. Stream bank and riparian zones were assessed on the left and right side of the stream separately. Right and left banks were determined when looking downstream. Both in-stream habitat and stream bank assessments were done for an area five meters either side of each transect. The stream bank was the area between the wetted edge of the stream and point of bank full (the point were the stream would leave its banks at flood stage). The riparian zone was assessed for an area 10 m^2 centered on each transect and starting at the bank full mark of the stream. Coverage of vegetation, woody debris and other structures were determined for in-stream, stream bank and riparian areas. Substrate type and embeddedness were determined and recorded for both in-stream and stream bank areas. The occurrence of filamentous algae, floating vegetation, rooted vascular plants and large woody debris were recorded. Upper and lower bank stability, severity of grazing damage if any and overall assessment of buffer zone condition was also made for each side of a transect. The depth of the Thalweg and substrate present at the point of the Thalweg were recorded during the 2003 survey.

2.3 Statistical Analysis Methods

Aquatic Invertebrate Analysis.--The invertebrate indices for the Niobrara River were compared graphically using means and an estimate of variance. This analytical approach was chosen over other statistical analysis options because of the imbalance among years in the number of samples collected. Specifically, in 1989 and 1996 when samples were collected on only one date (Appendix A). During 1997–2004, samples were collected on three different dates within each year, exception being 1998 when samples were collected on only two dates. Also, during 1997 samples were not collected in August from the middle site at Agate. Between 1996 and 1998 and again in 2002 less than five Hester-Dendy samplers were recovered during some sampling events. Spring flooding washed some samplers down stream and late season droughts have resulted in samplers resting in the mud on the bottom. Some samplers may have also been affected by debris washing against them during deployment.

Annual means and standard errors were calculated from means for each sample site and date. These means and standard errors were graphed and used to make annual water quality comparisons for the Niobrara River within the monument. As more data is collected, annual variations and trends in the water quality of the Niobrara River will be investigated using more rigorous statistical methods. Both, the correlation of data collected at the same site through time and the lack of independence of samples collected at a site on any given date will be considered in this future design.

In-stream Habitat and Riparian Condition Assessment Analysis.--Annual means were calculated for parameters measured within the stream reach. Using these means an overall two-year mean and standard error for each parameter was calculated. Mean parameter values give us a baseline from which to assess the influences of the physical and chemical environment on the invertebrate communities within the Niobrara River. As more data is collected, the relationship between in-stream habitat and riparian conditions with aquatic invertebrate communities in the Niobrara River will be investigated using more rigorous correlation analysis.

3.0 RESULTS

Aquatic Invertebrates.--The annual aquatic invertebrate indices calculated for the Niobrara River at Agate Fossil Beds National Monument, Nebraska are reported on Table 2 and displayed in Figure 2. The raw data are reported by sampling event and site in Appendix A as well. Year 1989 is represented by only five replicates collected at Agate Spring Ranch on 12 July (Appendix A). Therefore, 1989 data cannot serve as baseline data for change comparisons with other years. The 1989 data serves only as a reference to conditions at Agate Spring Ranch at that time.

Table 2. Mean (± SE) metric values for the aquatic invertebrate communities in the Niobrara River at Agate Fossil Beds National Monument, Nebraska from 1989 to 2004.

	Mean (SE)									
Aquatic Invertebrate Index	1989 n = 1	1996 n = 2	1997 n = 8	1998 n = 6	1999 n = 9	2000 n = 9	2001 n = 9	2002 N = 9	2003 n = 9	2004 n = 9
Density	3468.25 (na)	1238.97 (95.80)	3700.35 (718.12)	5077.14 (1270.85)	3733.29 (718.73)	5501.02 (1447.74)	5923.69 (755.65)	2697.17 (207.95)	3784.95 (868.94)	4123.91 (593.41)
Family Biotic Index	5.22 (na)	4.22 (0.18)	3.51 (0.26)	5.25 (0.47)	3.50 (0.20)	2.92 (0.14)	3.74 (0.25)	4.00 (0.23)	4.82 (0.33)	5.38 (0.41)
Genus Diversity	1.73 (na)	1.12 (0.21)	1.32 (0.09)	1.54 (0.20)	1.43 (0.13)	1.06 (0.09)	1.57 (0.09)	1.55 (0.07)	1.71 (0.13)	1.94 (0.11)
Genus Richness	15.60 (na)	9.90 (0.30)	14.54 (1.52)	12.16 (1.85)	16.76 (1.95)	9.07 (0.46)	12.33 (0.74)	10.51 (0.58)	12.78 (1.01)	14.56 (0.90)
Genus Evenness	0.63 (na)	0.48 (0.08)	0.52 (0.05)	0.64 (0.03)	0.52 (0.04)	0.49 (0.05)	0.63 (0.03)	0.67 (0.02)	0.67 (0.03)	0.73 (0.02)
EPT Richness	5.00 (na)	4.80 (0.20)	5.75 (0.67)	3.23 (0.55)	6.31 (0.31)	5.53 (0.39)	5.67 (0.24)	5.20 (0.21)	4.34 (0.26)	3.58 (0.37)

Since 1996, annual invertebrate densities (Fig. 2a) or the number of individuals present per sample, reported as individuals per m^2 demonstrated a three year cyclic phenomena. Invertebrate density declined in 1996, 1999 and 2002 followed by rebounds in the two years following each decline. Based on means and overlapping standard errors, average densities were significantly lower in years of decline than other years. However, average densities were similar across all other years with the exception of 2001 when density was significantly higher than all years but 2000.

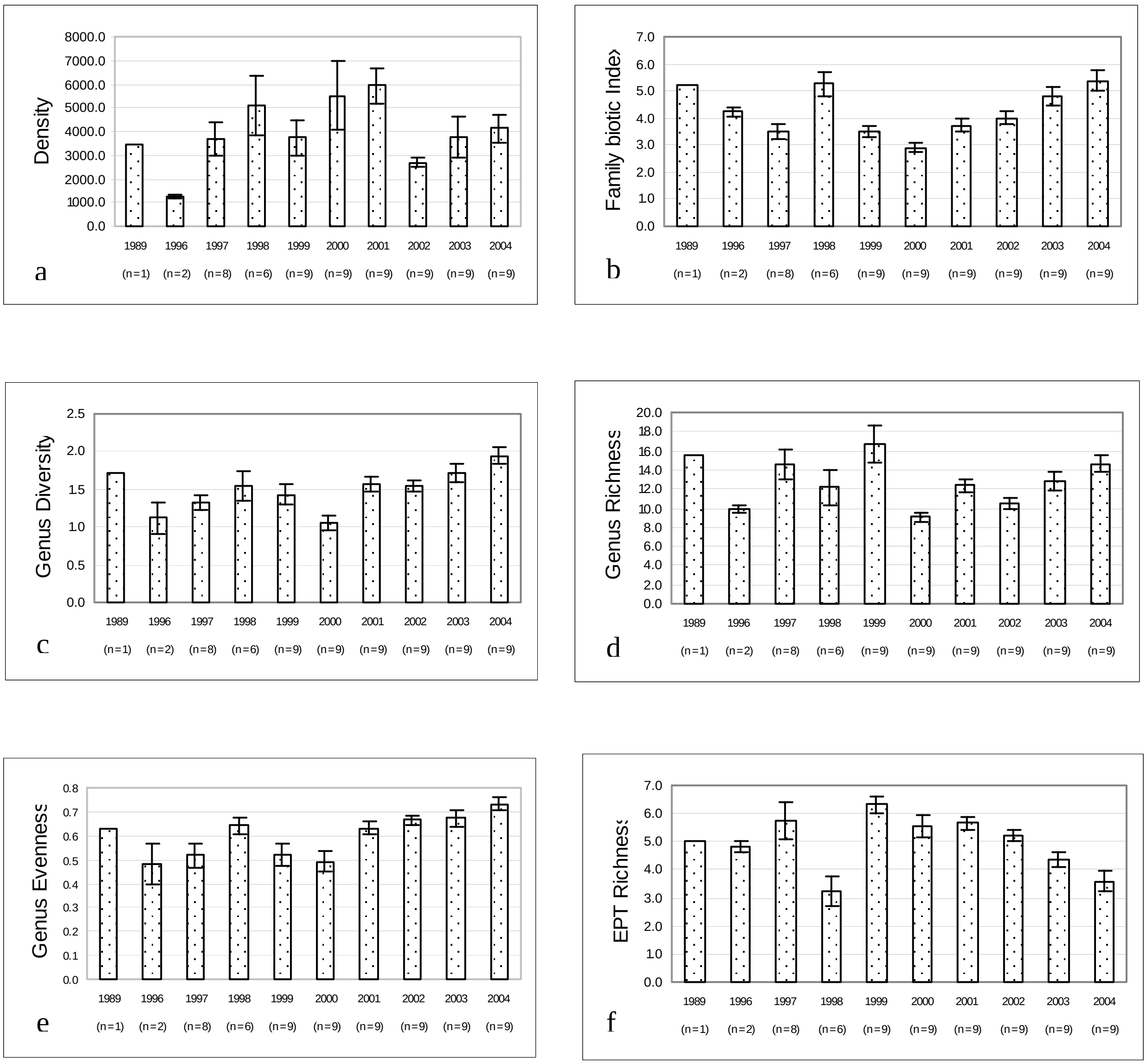

Figure 2. Mean (± SE) metric values for the aquatic invertebrate communities in the Niobrara River at Agate Fossil Beds National Monument, Nebraska from 1989 to 2004.

The Family Biotic Index values (Fig. 2b) suggests that water quality improved from 1996 to 1997 then declined sharply in 1998. Family Biotic Index values improved again in 1999 and

2000, but show a declining trend in years thereafter. EPT Richness values (Fig. 2f) provided a mirror image of Family Biotic Index values. As pollution intolerant EPT taxa declined, tolerant Chironomidae species influence on the Family Biotic Index values increased. Thus, Family Biotic Index values increased as EPT Richness declined. Therefore, both Family Biotic Index and EPT richness suggest that water quality in the Niobrara River at Agate Fossil Beds National Monument has declined slightly in quality since 1999-2000.

Genus Diversity (Fig. 2c), Genus Richness (Fig. 2d) and Genus Evenness (Fig. 2e) values though variable, suggest that water quality was improving in the Niobrara River until 2000 when it declined significantly. After 2000, water quality again improved each year based on results from these same three metrics.

In-stream Habitat and Riparian Condition Assessment Analysis.--Average habitat conditions for the Niobrara River at Agate Fossil Beds National Monument, Nebraska during 2002-2003 are shown in Table 3. Flow of the river was determined to be low to moderate with no recent rain events recorded before our assessments. The fluctuation rating for the river was determined to be minor to moderate. Sinuosity of the river is moderate to high.

Table 3. Mean (± SE) values for habitat parameters measured in the Niobrara River at Agate Fossil Beds National Monument, Nebraska in 2002 and 2003.

	Mean	Std. Err	Minimum	Maximum	Range
	Water chemistry parameter				
Water temperature (C^o)	20.55	1.45	19.10	22.00	2.90
Dissolved oxygen (mg/l)	7.37	0.07	7.30	7.43	0.13
Conductivity (uS/cm)	355.75	13.25	342.50	369.00	26.50
pH	8.07	0.01	8.06	8.07	0.01
Water clarity (cm)	24.00	4.80	28.80	28.80	9.60
	In-stream habitat parameter				
Stream width (m)	2.69	0.40	1.80	3.50	1.70
Thalweg depth (m)—2003 only	0.65	--	0.38	1.20	0.82
Canopy cover (%)	0.00	0.00	0.00	0.00	0.00
In-stream vegetation cover (%)	20.05	11.55	1.00	62.50	61.50
Small woody debris cover (%)	0.00	0.00	0.00	0.00	0.00
Overhanging vegetation cover (%)	20.14	12.68	1.00	62.50	61.50
Undercut bank (%)	14.16	9.11	0.00	62.50	62.50
Boulder cover (%)	0.00	0.00	0.00	0.00	0.00
Artificial structure cover (%)	0.00	0.00	0.00	0.00	0.00
	Stream bank parameter				
Height (m)	0.35	0.12	0.08	1.10	1.02
Slope (^{o})	23.82	5.77	5.00	60.00	55.00
Grass/forb cover (%)	64.28	4.01	3.50	85.00	81.5
Shrub/vine cover (%)	0.00	0.00	0.00	0.00	0.00
Understory trees cover (%)	0.00	0.00	0.00	0.00	0.00
Overstory tree cover (%)	0.00	0.00	0.00	0.00	0.00
Bare soil cover (%)	53.09	5.55	3.50	85.00	81.5
Bare rock cover (%)	0.00	0.00	0.00	0.00	0.00
Woody debris cover (%)	0.00	0.00	0.00	0.00	0.00
	Riparian parameter				
Grass/forb cover (%)	73.52	10.45	37.5	85.00	47.50
Shrub/vine cover (%)	0.00	0.00	0.00	0.00	0.00
Tree seedling cover (%)	0.00	0.00	0.00	0.00	0.00
Understory tree cover (%)	0.00	0.00	0.00	0.00	0.00
Overstory tree cover (%)	0.00	0.00	0.00	0.00	0.00

Excessive sedimentation and algae growth as well as channel alteration were not noted within the assessment reach. Riffles were absent from the reach as well. Therefore, the pool/riffle/run/bend ratio was high, greater than 26. Class 1 and class 2 pools were observed in the reach in 2002 and all four classes were observed in 2003, a year of higher rain fall. Stream degradation was minor within the reach assessed. The condition of the buffer zone along the reach was good to excellent, mostly excellent and grazing damage was not observed.

Average water quality measurements taken at a representative location along the assessment reach are given in Table 3. These measurements were not effected by runoff from recent rain events or return flow. Stream discharge within the reach averaged 0.12 m^3/s and average stream depth at the point discharge was 0.32 m. Average Thalweg depth for the total reach was 0.65 m. Silt made up over 61 % of the substrate within the reach followed by gravel (36%) and clay (3%). The lack of large substrate materials, those greater than 64.0 mm in diameter precluded us from measuring substrate embeddedness. However, embeddedness would have been high if any large substrate particles were present. Figure 3 illustrates the average depth and flow at ¼, ½ and ¾ of the distance across the river.

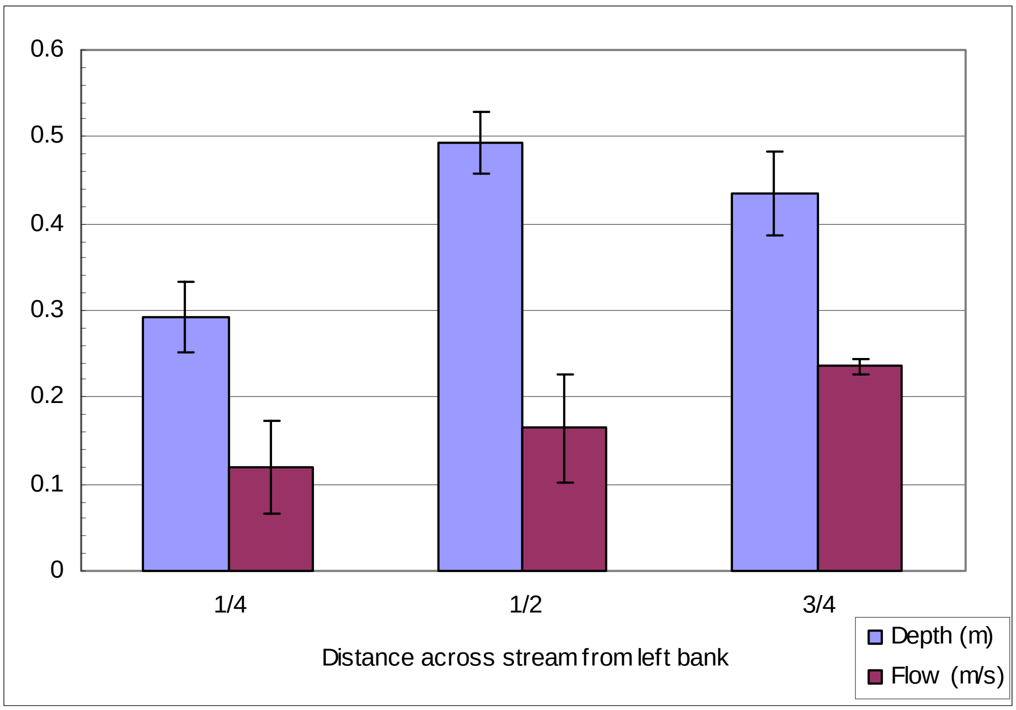

Figure 3. Mean (±SE) stream depth and flow at ¼, ½ and ¾ of the way across the Niobrara River from left bank. Measurements were taken within Agate Fossil Beds National Monument, Nebraska in 2002-2003.

Average cover of vegetation, brush and small woody debris, overhanging vegetation, undercut banks, boulders and artificial structures in the Niobrara river within our assessment reach are given in Table 3. Within the reach, canopy cover is non-existent above the river and large wood debris within it. Rooted vascular plants were encountered occasionally to commonly within the reach. Rooted vascular plants were the only vegetative form present in the river within the reach. Filamentous algae and floating vegetation were not observed.

Stream bank stability along the reach was good to excellent, mostly excellent. The dominant substrate was silt and vegetation cover grass/forbs (Table 3). The riparian area along the stream bank was dominated by upland-prairie (40 %), wetland (33 %) and riparian-prairie (27 %).

4.0 DISCUSSION

In summary, it appears that water in the Niobrara River at Agate Fossil Beds National Monument, Nebraska, while fluctuating slightly is of generally good quality and may have improved in recent years. Both our results and those of a research summary by the Water Resource Division (1999) of the National Park Service for studies completed between 1952 and 1993 support this conclusion. Water Resources Division (1999) identified only a few instances when water quality has dropped below recognized standards between 1952 and 1993. Current threats to water quality from above the monument and within it appear to be minimal. Cattle grazing in the watershed above the monument and a small feedlot bordering the monument are the main threats. When looking at results of our monitoring efforts it is important to keep in mind that our data from the Niobrara River has not been compared to reference streams in the region, and the observed changes are relative to conditions observed previously. However, the Niobrara River at Agate Fossil Beds National Monument may very well serve as a high quality reference stream for that region of Nebraska.

In 2002, when we last reported on the conditions of the Niobrara River at Agate Fossil Beds National Monument, Nebraska we suggested that an expansion of water quality monitoring within the Monument should include chemical and physical measures, as well as the biotic measure. This would help identify and document any future declines in water quality, if they occur. Both chemical and physical measures serve to help identify potential causes for changes in biotic communities, as well as serve as indicator of changing water conditions themselves. Monitoring of both chemical and physical measures where initiated since 2002. Results from these measured parameters also support our conclusions that water quality is good and threats to the system are minimal.

The Niobrara River is a typical plains river, with the dominant stream bed substrate being silt which limits the diversity of invertebrates that can utilize the stream. Most water quality measurements were within acceptable levels based on the rivers geographic location. Water clarity is relatively low with the highest quality reading being 28.8 cm. Low water clarity can limit the amount of phytoplankton and macrophytes in the river. Low water clarity may negatively impact populations of aquatic invertebrates by limiting their food source. Rooted vegetation, mainly the exotic *Iris pseudacorus* provided most of the in-stream structure and detritus for the system. Average discharge for the section of the Niobrara River that flows through the park remained relatively unchanged during the two years of the survey, suggesting flow is stable within our assessment reach.

5.0 MANAGEMENT IMPLICATIONS

The generally high quality conditions of the Niobrara River within Agate Fossil Beds National Monument, Nebraska suggest little to no active management should take place to improve water quality or improve in-stream habitat and riparian zone conditions. The diversity of aquatic invertebrates that utilize the river may always appear low when compared to other systems. With the majority of the stream bed consisting of silt, a suppressed aquatic invertebrate community should be expected and considered a natural condition of the Niobrara River, a prairie streams system. The long history and continuing efforts with water quality monitoring in the Niobrara River provides a sound tool to recognize both a rapid deterioration of water quality as well as a chronic decline.

6.0 ACKNOWLEDGEMENTS

We would like to thank all of those who have contributed to aquatic invertebrate monitoring at Agate Fossil Beds National Monument, Nebraska over the years. In particular, we would like to thank Bob Manasek (Natural Resource Manager), Lil Morava and the numerous seasonal employees who assisted with invertebrate sampling and stream reach assessments.

7.0 LITERATURE CITED

Cairns, J., Jr. and J.R. Pratt. 1993. A history of biological monitoring using benthic macroinvertebrates. Pages 10-27 *In* Freshwater biomonitoring and benthic macroinvertebrates. D.M. Rosenberg and V.H. Resh, editors. Chapman and Hall , New York, New York.

Harris, M.A., B.C. Kondratieff, and T.P. Boyle. 1991. Macroinvertebrate assemblages and water quality in six National Park units in the Great Plains. National Park Service, Water Resources Division, Fort Collins, Colorado.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. Journal of the North American Benthological Society 7:65-68.

Kuchler, A.W. 1964. Potential natural vegetation map. National Atlas of the United States of America, U.S. Geological Survey.

Omernick, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geography 77:118-125.

Peitz, D.G. draft. Aquatic resource monitoring for National Park Service units with significant prairie stream components. National Park Service, The Heartland I&M Network and Prairie Cluster Prototype Monitoring Program, Republic, Missouri. 00pp.

Peterson, J.T. 1996. Suggested Biomonitoring protocol and status of stream quality at six Great Plains National Parks. University of Missouri, Columbia. 70pp.

Peterson, J.T., W.M. Rizzo, E.D. Schneider, and G.D. Willson. 1999. Macroinvertebrate biomonitoring protocol for four prairie streams. U.S. Geological Survey, Biological Resources Division, Northern Prairie Wildlife Research Center, Missouri Field Station, University of Missouri-Columbia. 45pp.

Pielou, E.C. 1966. The measurement of diversity in different types of biological conditions. The Journal of Theoretical Biology 13:131-144.

Plafkin, J.L., M.T. Barbour, K..D. Porter, S.K. Gross, and R.M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, D.C., EPA 444-4-89-001.

Resh, V.H. and G. Grodhaus. 1983. Aquatic insects in urban environments. Pages 247-276 *In* Urban Entomology: Interdisciplinary Perspectives. G.W. Frankie and C.S. Koehler, editors. Praeger Publishers, New York.

Rosenberg, D.M. and V.H. Resh. 1993. Introduction to freshwater biomonitoring and benthic macroinvertebrates. Pages 1-9 *In* Freshwater biomonitoring and benthic macroinvertebrates. D.M. Rosenberg and V.H. Resh, editors. Chapman and Hall, New York, New York.

Shannon, C.E. and W. Weaver. 1949. The mathematical theory of communication. University of Illinois Press, Urbana. 177 pp.

Stubbendieck, J.L. and G.D. Willson. 1986. An identification of prairie in National Park units in the Great Plains. National Park Service, Midwest Regional Office, Omaha, Nebraska.

Water Resources Division. 1999. Baseline water quality data inventory and Analysis: Agate Fossil Beds National Monument. National Park Service, Water Resources Division, Fort Collins, Colorado.

Appendix A. Mean (+ Std Dev) values for the aquatic invertebrate metrics calculated for the Niobrara River, Agate Fossil Beds National Monument, Nebraska by sample date and sample site.

Sample Date	N	Total Taxa Density	Total Taxa Diversity	Total Taxa Richness	Total Taxa Evenness	FBI	Genus Diversity	Genus Richness	Genus Evenness	EPT Richness
					Agate Spring Ranch					
7/12/89	5	3468.25 (468.23)	1.73 (0.10)	15.60 (1.17)	0.63 (0.03)	5.22 (0.11)	1.73 (0.10)	15.60 (1.17)	0.63 (0.03)	5.00 (0.45)
7/17/96	5	1334.77 (197.52)	0.91 (0.14)	9.60 (1.21)	0.40 (0.04)	4.04 (0.04)	0.91 (0.14)	9.60 (1.21)	0.40 (0.04)	5.00 (0.63)
7/31/97*	5	3246.50 (309.57)	1.47 (0.19)	19.20 (2.99)	0.50 (0.04)	3.55 (0.07)	1.47 (0.19)	19.20 (2.99)	0.50 (0.04)	8.40 (0.93)
8/27/97	5	3407.97 (566.35)	1.38 (0.09)	12.80 (1.07)	0.55 (0.04)	3.22 (0.14)	1.38 (0.09)	12.80 (1.07)	0.55 (0.04)	5.20 (0.37)
9/24/97	5	2251.88 (372.02)	1.41 (0.13)	14.80 (1.88)	0.53 (0.03)	3.69 (0.13)	1.41 (0.13)	14.80 (1.88)	0.53 (0.03)	7.00 (0.71)
7/2/98	5	4540.37 (711.91)	2.15 (0.09)	18.60 (1.69)	0.74 (0.01	5.02 (0.14)	2.15 (0.09)	18.60 (1.69)	0.74 (0.01)	4.20 (0.49)
9/1/98*	4	3912.81 (1518.29)	0.85 (0.10)	6.00 (1.41)	0.60 (0.15)	3.39 (0.55)	0.85 (0.10)	6.00 (1.41)	0.60 (0.15)	3.50 (0.87)
7/20/99	5	2157.16 (349.49)	1.13 (0.08)	9.20 (1.46)	0.53 (0.02)	3.89 (0.08)	1.13 (0.08)	9.20 (1.46)	0.53 (0.02)	5.80 (0.73)
8/23/99	5	4703.98 (547.16)	1.00 (0.05)	12.20 (1.16)	0.41 (0.03)	2.87 (0.13)	1.00 (0.05)	12.20 (1.16)	0.41 (0.03)	6.40 (0.51)
9/27/99*	5	3496.23 (121.80)	0.94 (0.12)	15.20 (1.24)	0.34 (0.03)	2.72 (0.12)	0.94 (0.12)	15.20 (1.24)	0.34 (0.03)	5.60 (0.68)
7/18/00	5	4111.95 (562.84)	1.26 (0.06)	8.60 (1.44)	0.61 (0.04)	3.25 (0.10)	1.26 (0.06)	8.60 (1.44)	0.61 (0.04)	6.80 (0.58)
8/22/00	5	4757.80 (311.09)	0.87 (0.09)	7.20 (1.20)	0.45 (0.03)	2.72 (0.10)	0.87 (0.09)	7.20 (1.20)	0.45 (0.03)	4.40 (0.51)
9/18/00	5	3427.34 (264.23)	0.76 (0.09)	7.60 (0.75)	0.38 (0.03)	2.61 (0.07)	0.76 (0.09)	7.60 (0.75)	0.38 (0.03)	3.40 (0.24)
7/24/01*	5	6820.24 (835.64)	1.38 (0.18)	11.60 (1.25)	0.56 (0.05)	3.14 (0.27)	1.38 (0.18)	11.60 (1.25)	0.56 (0.05)	6.20 (0.49)
8/21/01	5	5166.85 (758.37)	1.03 (0.09)	7.60 (0.60)	0.51 (0.03)	2.88 (0.17)	1.03 (0.09)	7.60 (0.60)	0.51 (0.03)	4.40 (0.40)
9/25/01	5	4374.60 (860.77)	1.54 (0.05)	10.60 (0.87)	0.66 (0.04)	3.45 (0.14)	1.54 (0.05)	10.60 (0.87)	0.66 (0.04)	4.60 (0.40)
7/11/02	4	3568.35 (684.95)	1.43 (0.21)	9.00 (2.00)	0.66 (0.10)	3.90 (0.22)	1.43 (0.21)	9.00 (2.00)	0.66 (0.10)	5.00 (0.82)
8/20/02	5	2273.41 (933.53)	1.16 (0.16)	7.80 (1.64)	0.57 (0.05)	3.05 (0.20)	1.16 (0.16)	7.80 (1.64)	0.57 (0.05)	4.00 (1.22)
9/16/02	5	2286.33 (594.36)	1.63 (0.14)	12.40 (3.78)	0.66 (0.05)	4.38 (0.48)	1.63 (0.14)	12.40 (3.78)	0.66 (0.05)	5.00 (1.87)
7/15/03	5	2178.69 (895.78)	1.51 (0.39)	12.60 (1.67)	0.59 (0.13)	4.18 (0.33)	1.51 (0.39)	12.60 (1.67)	0.59 (0.13)	5.00 (1.41)
8/25/03	5	3423.04 (1125.26)	1.07 (0.20)	7.20 (1.64)	0.55 (0.09)	2.98 (0.31)	1.07 (0.20)	7.20 (1.64)	0.55 (0.09)	3.8 (0.45)
9/29/03	5	9220.67 (3005.21)	1.22 (0.39)	10.40 (2.70)	0.52 (0.11)	5.20 (0.47)	1.22 (0.39)	10.40 (2.70)	0.52 (0.11)	5.20 (1.30)
7/20/04	5	3293.86 (583.26)	1.64 (0.17)	10.20 (3.56)	0.73 (0.11)	4.03 (0.55)	1.63 (0.17)	10.00 (3.32)	0.74 (0.11)	5.00 (2.35)
8/18/04	5	3698.60 (1564.22)	1.32 (0.20)	10.60 (2.61)	0.57 (0.08)	3.11 (0.26)	1.32 (0.20)	10.60 (2.61)	0.57 (0.08)	5.00 (1.00)
9/27/04	5	5507.00 (3070.53)	1.80 (0.37)	13.60 (2.30)	0.69 (0.10)	5.00 (0.22)	1.80 (0.37)	13.60 (2.30)	0.69 (0.10)	4.80 (0.84)

Appendix A. continued.

Sample Date	N	Total Taxa Density	Total Taxa Diversity	Total Taxa Richness	Total Taxa Evenness	FBI	Genus Diversity	Genus Richness	Genus Evenness	EPT Richness
					Agate East					
7/17/96	5	1143.16 (291.48)	1.33 (0.23)	10.20 (1.02)	0.57 (0.08)	4.40 (0.28)	1.33 (0.23)	10.20 (1.02)	0.57 (0.08)	4.60 (0.24)
7/31/97**	5	6785.79 (1793.84)	0.76 (0.10)	14.00 (2.05)	0.30 (0.04)	2.63 (0.16)	0.76 (0.10)	14.00 (2.05)	0.30 (0.04)	6.00 (0.45)
8/27/97	4	4806.24 (1079.70)	1.12 (0.06)	13.00 (1.96)	0.45 (0.04)	3.17 (0.10)	1.12 (0.06)	13.00 (1.96)	0.45 (0.04)	5.50 (0.87)
9/24/97	5	5593.11 (948.49)	1.57 (0.17)	21.20 (2.27)	0.52 (0.06)	3.45 (0.23)	1.57 (0.17)	21.20 (2.27)	0.52 (0.06)	6.40 (0.40)
7/2/98	5	2712.59 (301.09)	1.25 (0.21)	8.60 (1.29)	0.58 (0.09)	4.67 (0.22)	1.25 (0.21)	8.60 (1.29)	0.58 (0.09)	2.80 (0.37)
9/1/98*	5	3677.07 (140.58)	2.01 (0.16)	14.80 (1.24)	0.75 (0.04)	6.18 (0.27)	2.01 (0.16)	14.80 (1.24)	0.75 (0.04)	5.20 (0.92)
7/20/99	5	6385.36 (832.86)	2.13 (0.08)	26.40 (2.89)	0.66 (0.02)	4.12 (0.08)	2.13 (0.08)	26.40 (2.89)	0.66 (0.02)	7.40 (0.51)
8/23/99	5	7642.63 (428.63)	1.30 (0.02)	24.60 (1.08)	0.41 (0.01)	3.20 (0.13)	1.30 (0.02)	24.60 (1.08)	0.41 (0.01)	8.00 (0.89)
9/27/99*	5	3804.09 (925.47)	1.39 (0.26)	20.60 (1.29)	0.46 (0.08)	3.20 (0.36)	1.39 (0.26)	20.60 (1.29)	0.46 (0.08)	6.60 (0.60)
7/18/00	5	7384.28 (732.86)	1.11 (0.12)	10.80 (0.37)	0.47 (0.06)	2.72 (0.11)	1.11 (0.12)	10.80 (0.37)	0.47 (0.06)	7.20 (0.37)
8/22/00	5	15801.94 (2463.98)	0.56 (0.02)	10.20 (1.02)	0.24 (0.01)	2.34 (0.03)	0.56 (0.02)	10.20 (1.02)	0.24 (0.01)	6.20 (0.58)
9/18/00*	5	6897.74 (619.99)	1.03 (0.06)	11.20 (1.07)	0.43 (0.01)	2.76 (0.05)	1.03 (0.06)	11.20 (1.07)	0.43 (0.01)	5.20 (0.37)
7/24/01*	5	4387.51 (1071.47)	1.77 (0.13)	12.80 (1.56)	0.70 (0.03)	3.80 (0.26)	1.77 (0.13)	12.80 (1.56)	0.70 (0.03)	6.20 (0.49)
8/21/01	5	8473.63 (1573.17)	1.46 (0.08)	13.60 (0.93)	0.56 (0.03)	3.12 (0.09)	1.46 (0.08)	13.60 (0.93)	0.56 (0.03)	6.20 (0.20)
9/25/01	5	8942.95 (877.50)	1.62 (0.11)	13.20 (1.20)	0.63 (0.03)	5.28 (0.17)	1.62 (0.11)	13.20 (1.20)	0.63 (0.03)	5.60 (0.40)
7/11/02	5	2389.67 (680.62)	1.77 (0.24)	12.80 (2.68)	0.70 (0.06)	3.93 (0.35)	1.77 (0.24)	12.80 (2.68)	0.70 (0.06)	6.00 (0.71)
8/20/02	5	3836.38 (876.40)	1.30 (0.12)	10.00 (3.16)	0.58 (0.04)	3.01 (0.19)	1.30 (0.12)	10.00 (3.16)	0.58 (0.04)	5.80 (0.84)
9/16/02	5	2443.49 (585.64)	1.50 (0.18)	9.20 (1.30)	0.68 (0.09)	4.58 (0.53)	1.50 (0.18)	9.20 (1.30)	0.68 (0.09)	4.60 (0.55)
7/15/03	5	2973.09 (1240.91)	2.22 (0.21)	17.00 (1.41)	0.78 (0.06)	4.28 (0.43)	2.22 (0.21)	17.00 (1.41)	0.78 (0.06)	5.40 (0.55)
8/25/03	4	1700.75 (1266.13)	1.76 (0.39)	13.00 (4.08)	0.69 (0.13)	4.05 (0.68)	1.76 (0.39)	13.00 (4.08)	0.69 (0.13)	4.25 (1.89)
9/29/03	5	1888.05 (766.63)	1.76 (0.17)	11.80 (2.95)	0.72 (0.03)	5.55 (0.13)	1.76 (0.17)	11.80 (2.95)	0.72 (0.03)	3.00 (0.71)
7/20/04	5	1601.72 (879.03)	2.40 (0.15)	17.80 (2.59)	0.84 (0.04)	5.57 (0.58)	2.40 (0.15)	17.80 (2.59)	0.84 (0.04)	2.80 (0.45)
8/18/04	5	2686.76 (992.35)	1.88 (0.47)	14.20 (5.40)	0.72 (0.09)	5.72 (1.09)	1.88 (0.47)	14.20 (5.40)	0.72 (0.09)	3.60 (1.52)
9/27/04	5	2738.43 (1002.80)	2.14 (0.25)	16.40 (2.30)	0.77 (0.06)	5.32 (0.50)	2.14 (0.25)	16.40 (2.30)	0.77 (0.06)	3.40 (1.52)
					Agate Middle					
7/31/97*	3	3272.34 (526.50)	1.34 (0.17)	14.33 (0.67)	0.50 (0.06)	3.24 (0.24)	1.34 (0.17)	14.33 (0.67)	0.50 (0.06)	5.67 (1.33)
9/24/97*	5	238.97 (81.58)	1.50 (0.16)	7.00 (1.26)	0.80 (0.05)	5.13 (0.57)	1.50 (0.16)	7.00 (1.26)	0.80 (0.05)	1.80 (0.80)
7/2/98*	4	11297.09 (1573.97)	1.48 (0.14)	13.75 (0.85)	0.56 (0.04)	6.50 (0.15)	1.48 (0.14)	13.75 (0.85)	0.56 (0.04)	1.50 (0.50)
9/1/98*	5	4322.93 (947.90)	1.48 (0.19)	11.20 (1.07)	0.62 (0.08)	5.78 (0.63)	1.48 (0.19)	11.20 (1.07)	0.62 (0.08)	2.20 (0.80)

Appendix A. continued.

Sample Date	N	Total Taxa Density	Total Taxa Diversity	Total Taxa Richness	Total Taxa Evenness	FBI	Genus Diversity	Genus Richness	Genus Evenness	EPT Richness
7/20/99*	5	1498.39 (262.42)	1.91 (0.13)	12.60 (1.40)	0.76 (0.02)	4.41 (0.31)	1.91 (0.13)	12.60 (1.40)	0.76 (0.02)	5.40 (0.60)
8/23/99*	5	2150.70 (287.17)	1.53 (0.12)	15.40 (1.03)	0.56 (0.04)	3.19 (0.17)	1.53 (0.12)	15.40 (1.03)	0.56 (0.04)	6.40 (0.24)
9/27/99**	5	1761.03 (443.15)	1.52 (0.10)	14.60 (0.75)	0.57 (0.04)	3.90 (0.31)	1.52 (0.10)	14.60 (0.75)	0.57 (0.04)	5.20 (0.20)
7/18/00*	5	1451.02 (519.43)	1.44 (0.19)	8.60 (1.63)	0.68 (0.05)	3.76 (0.03)	1.44 (0.19)	8.60 (1.63)	0.68 (0.05)	5.80 (1.16)
8/22/00*	5	3823.47 (700.54)	1.21 (0.04)	8.60 (1.17)	0.58 (0.03)	2.92 (0.08)	1.21 (0.04)	8.60 (1.17)	0.58 (0.03)	5.80 (0.86)
9/18/00*	5	1853.61 (436.72)	1.27 (0.15)	8.80 (0.92)	0.59 (0.07)	3.18 (0.24)	1.27 (0.15)	8.80 (0.92)	0.59 (0.07)	5.00 (0.84)
7/24/01*	5	3349.84 (730.98)	2.05 (0.09)	15.40 (0.24)	0.75 (0.03)	4.18 (0.25)	2.05 (0.09)	15.40 (0.24)	0.75 (0.03)	6.20 (0.66)
8/21/01*	5	3375.67 (958.62)	1.68 (0.05)	12.60 (1.75)	0.68 (0.03)	3.51 (0.07)	1.68 (0.05)	12.60 (1.75)	0.68 (0.03)	6.20 (0.86)
9/25/01	5	8421.96 (1379.61)	1.65 (0.06)	13.60 (1.03)	0.64 (0.03)	4.30 (0.17)	1.65 (0.06)	13.60 (1.03)	0.64 (0.03)	5.40 (0.24)
7/11/02	5	3005.38 (1757.02)	1.74 (0.15)	10.80 (1.79)	0.74 (0.05)	4.85 (0.39)	1.74 (0.15)	10.80 (1.79)	0.74 (0.05)	5.60 (0.55)
8/20/02	5	2355.22 (647.04)	1.58 (0.13)	10.20 (2.68)	0.69 (0.05)	3.52 (0.14)	1.58 (0.13)	10.20 (2.68)	0.69 (0.05)	5.40 (0.89)
9/16/02	5	2116.25 (961.36)	1.79 (0.15)	12.40 (1.14)	0.71 (0.04)	4.73 (0.56)	1.79 (0.15)	12.40 (1.14)	0.71 (0.04)	5.40 (0.89)
7/15/03	5	2828.85 (1006.97)	2.24 (0.39)	16.00 (2.83)	0.81 (0.11)	5.77 (0.48)	2.24 (0.39)	16.00 (2.83)	0.81 (0.11)	4.60 (1.34)
8/25/03	5	2691.07 (1170.98)	1.79 (0.48)	11.6 (2.07)	0.73 (0.16)	5.62 (0.27)	1.79 (0.48)	11.60 (2.07)	0.73 (0.16)	3.60 (1.14)
9/29/03	5	7160.39 (7033.22)	1.87 (0.68)	15.40 (3.65)	0.68 (0.21)	5.79 (0.16)	1.87 (0.68)	15.40 (3.65)	0.68 (0.21)	4.20 (1.30)
7/20/04	5	6574.81 (6216.48)	2.20 (0.21)	16.40 (3.21)	0.79 (0.09)	6.68 (0.38)	2.20 (0.21)	16.40 (3.21)	0.79 (0.09)	2.20 (0.84)
8/18/04	5	4413.35 (2876.82)	2.02 (0.19)	16.00 (2.92)	0.73 (0.03)	7.02 (0.21)	2.02 (0.19)	16.00 (2.92)	0.73 (0.03)	2.80 (0.84)
9/27/04	5	6600.65 (5543.12)	2.08 (0.19)	16.20 (2.95)	0.75 (0.08)	6.02 (0.12)	2.07 (0.19)	16.00 (2.74)	0.75 (0.08)	2.60 (0.55)

* An event occurred during deployment that could potentially influence the results on this sample date (e.g. flood during sampler deployment).
** Two or more events occurred during deployment that could potentially influence the results on this sample date (e.g. flood during sampler deployment).